power generation group

Development of Fireside Corrosion Models for Advanced Combustion Systems

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State of Knowledge

Major Fireside Corrosion Mechanisms in Coal-Fired Boilers:

- **Furnace Walls**
  - Sulfidation (high-S coal, low-NOx & staged combustion)
  - Chlorination (high-Cl coal, low-NOx & staged combustion)
  - Corrosion fatigue cracking (large ΔT, large ΔCTE, high-Cl, high-S)
  - Oxidation

- **Superheaters/Reheaters**
  - Coal ash (hot) corrosion (high-S coal, liquid phase)
  - Sulfidation (high-S coal, internal attack)
  - Chlorination (high-Cl coal, liquid phase)
  - Carburization (high LOI, staged combustion)
  - Oxidation

State of Knowledge (cont.)

- Basic corrosion mechanisms reasonably understood
- Predictive equations available for furnace walls linking corrosion rate to T, Cr%, and [H_2S]
- Mechanism for extremely high furnace-wall wastage under staged combustion discovered
- Reliable, scientific prediction for coal ash corrosion on SH/RH is lacking
- No direct correlation of corrosion rate with coal chemistry!

Program Objectives

- Determine the effects of coal impurities on fireside corrosion
- Generate fireside corrosion database from long-term laboratory testing simulating modern coal-fired boiler conditions
- Develop corrosion models with predictive equations for lower furnace walls and SH/RH

Program Approach

- Select eight US coals from 24 candidates containing a wide range of impurities
- Burn coals in a pilot-scale combustion facility to produce desired fireside conditions
- Perform in-furnace gas and deposit sampling at furnace wall and superheater locations
- Expose samples of alloys and coatings to laboratory conditions to generate long-term corrosion data
- Correlate corrosion rates with coal impurities and formulate predictive equations for furnace walls and SH/RH

Program Major Tasks

- **Task 1** – Coal Selection, Procurement, and Handling
- **Task 2** – SBS-II Pilot Scale Combustion Testing
- **Task 3** – In-Furnace Gas and Deposit Sampling
- **Task 4** – Laboratory Corrosion Testing
- **Task 5** – Corrosion Model Development
- **Task 6** – Management and Reporting

Task 1 - Coal Selection, Procurement, and Handling

Approach

- Review coal databases and update commercial availability
- Select 24 common U.S. coals (bituminous, subbituminous, PRB, and lignite)
- Obtain coal samples and perform coal analysis for impurities if necessary
- Down-select 8 coals for pilot-scale combustion testing (Task 2)
- Procure, handle, store, and pulverize coals

Task 1 - Coal Selection, Procurement, and Handling

Potential Makeup of Eight U.S. Coals

- Three eastern bituminous with different S but comparable Na+K and Cl contents (e.g., IL#6 and Pit#8)
- One eastern bituminous with high Cl (e.g., >3000 ppm)
- One eastern bituminous with high alkaline earth metals (Ca and Mg)
- One western subbituminous with high alkali and alkaline earth metals (e.g., Decker and Spring Creek)
- One lignite with high ash and moisture (e.g., North Dakota)
- One TBD

Task 1 - Coal Selection, Procurement, and Handling

- **Coal Analyses**
  - Proximate
  - Ultimate
  - Ash
  - Grindability (HGI)
- **Coal Handling**
  - Partial drying
  - Storage
  - Pulverizing (70% < 200 mesh)
  - Transport
  - Delivery for testing (Task 2)

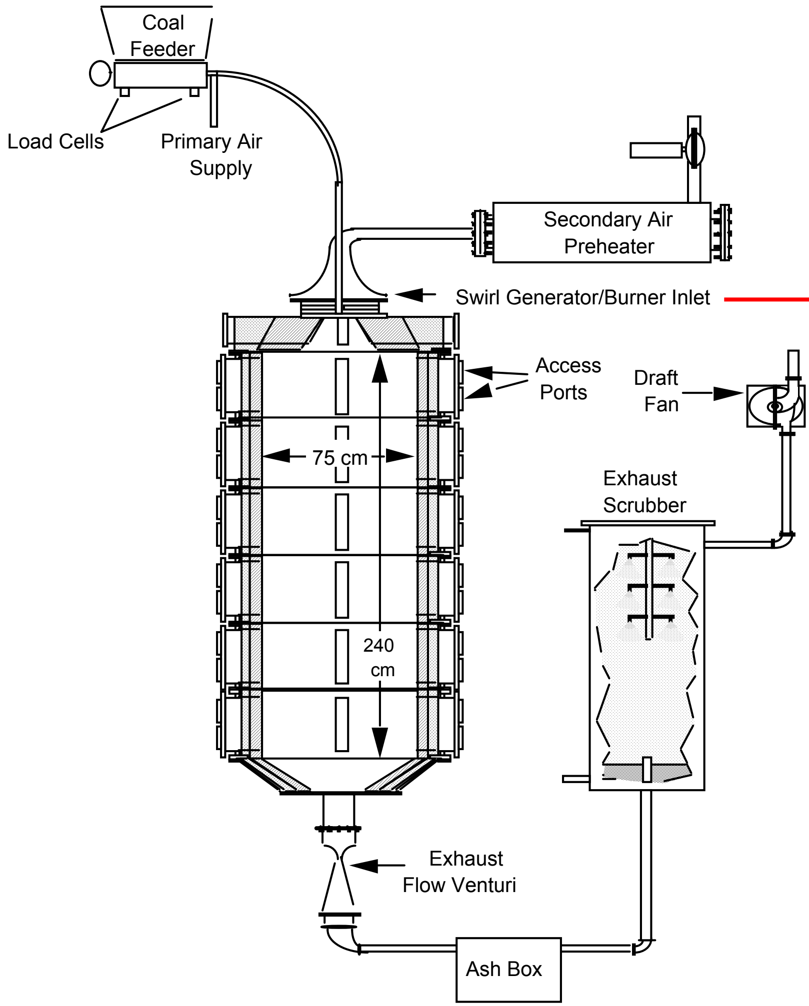
Task 2 – Pilot Scale Combustion Testing

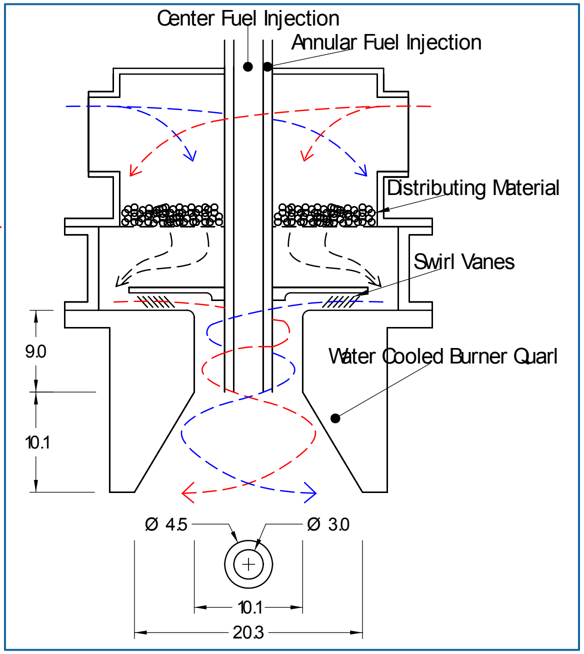
Approach

- Combustion testing of each coal using BYU pilot-scale combustion facility - **Burner Flow Reactor (BFR)**
- Staged combustion @0.85
- B&W CFD modeling to determine optimal combustion conditions for each coal
- Air split similar to utility boilers
- Flame temperature mapping
- Access ports for gas and deposit probing

Task 2 – Pilot Scale Combustion Testing

Burner Flow Reactor (BFR) – 0.6 MBtu/hr heat input





Variable Swirl Burner

Task 3 – Gas and Deposit Sampling

Approach

- Identify the corrosive environments adjacent to
  - Furnace Wall – low-NOx, staged combustion
  - SH/RH – molten salt, acid-base dissolution, fluxing
- Perform sampling at lower and upper furnace under realistic combustion conditions
  - Flue gases
  - Deposits
- Analyze gas and deposit samples for Task 4
  - Gases collected and analyzed online and offline
  - Deposits collected online and analyzed offline

Task 3 – Gas and Deposit Sampling

Gas Sampling

- Advanced gas analytical system to be employed
  - GC
  - FTIR
  - Horiba analyzer
  - Controlled condensation

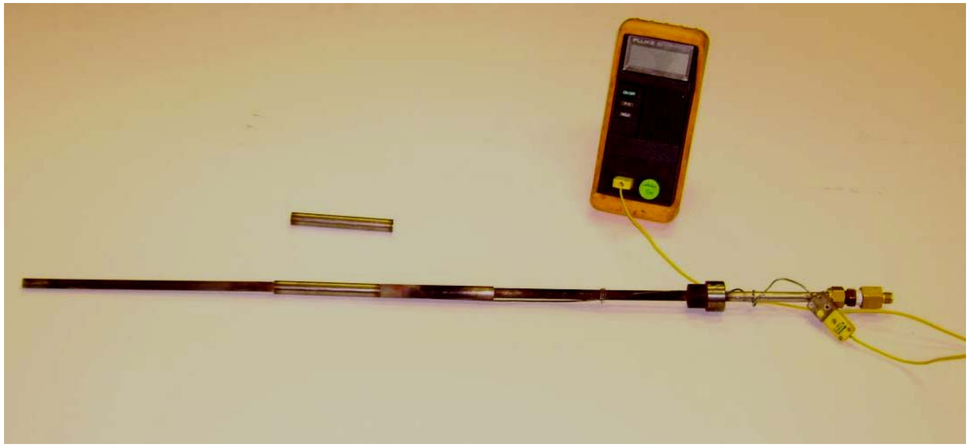
- Gas species
  - CO_2 SO_2 SO_3 NO_x H_2O O_2
    CO H_2S HCl H_2

- Water-cooled probe
  - Stainless steel construction
  - Heated above dew point
  - Particulate filter

Task 3 – Gas and Deposit Sampling

Deposit Sampling

- SS deposition probes
- Air-cooled for steep thermal gradient
- Sampling at burner zone and SH locations
- Probe T controlled at 800-1000^{o}F for burner zone
- Probe T controlled at 1100-1500^{o}F for SH



Task 4 – Laboratory Corrosion Testing

Approach

- Simulate furnace wall and SH conditions in laboratory
- Conditions based on Task 3 results
- Incorporate species of coal impurities into testing
- Long-term exposure to generate reliable corrosion database
- Evaluate performance of a wide range of alloy and coating compositions

Task 4 – Laboratory Corrosion Testing

- Two furnace facilities to run lower furnace and SH conditions in parallel
- Each test runs for 1000 hours
- A total of 11 boiler-tube alloys and weld overlays exposed in each test
- Duplicate samples for each material
  - Measure weight/thickness changes
  - X-sections
  - Optical and SEM/EDS examinations
- Investigate effect of metal temperatures on fireside corrosion
  - Furnace wall: 750^{o}F, 850^{o}F, 950^{o}F
  - SH: 1200^{o}F, 1300^{o}F, 1400^{o}F

Task 4 – Laboratory Corrosion Testing

Fireside Corrosion Testing Facility

Task 4 – Laboratory Corrosion Testing

Lower Furnace Materials of Interest

	Nominal Composition (wt%)										
Material	**C**	**Si**	**Mn**	**Fe**	**Cr**	**Ni**	**Mo**	**Al**	**Cu**	**P**	**S**	**Other**
SA178A	0.25	--	0.75	Bal.	--	--	--	0.07	--	0.022	0.005	--
SA213-T2	0.10	0.13	0.52	Bal.	0.72	0.06	0.48	0.004	0.07	0.01	0.016	--
SA213-T11	0.11	0.72	0.38	Bal.	1.01	--	0.49	--	--	0.012	0.013	--
SA213-T22	0.13	0.25	0.39	Bal.	2.12	0.13	0.99	--	--	0.008	0.004	--
SA213-T91	0.11	0.37	0.48	Bal.	8.29	0.14	1.03	--	0.18	--	--	.22V,.68Nb
SA213-T122				bal	12		0.4		1			2W
SA213-304L	0.01	0.48	1.82	Bal.	18.2	8.11	--	--	--	0.031	0.011	--
SA213-309	0.03	0.56	1.80	Bal.	22.3	14.8	0.12	--	0.13	0.022	0.001	--
SA213-310	0.06	0.68	1.94	Bal.	24.9	19.7	0.16	--	0.11	0.024	0.001	--
IN 52 Weld Overlay	--	0.36	--	9.25	29.2	59.9	--	--	--	--	--	1.29(Al+Ti)
IN 72 Weld Overlay	--	0.26	--	3.21	42.9	53.0	--	--	--	--	--	.61Ti

Task 4 – Laboratory Corrosion Testing

Materials for Superheater/Reheater Tests

	Typical Composition (wt%)										
Material	**C**	**Si**	**Mn**	**Fe**	**Cr**	**Ni**	**Mo**	**Ti**	**V**	**Nb**	**Co**	**Other**
304H	0.06	0.50	1.19	Bal.	16.5	8.23	--	--	--	--	--	--
Super 304H	0.08	0.25	0.45	Bal.	19.10	9.57	0.15	--	0.064	0.50	--	--
310 HCbN	0.05	0.36	1.18	Bal	25.6	20.0	--	--	--	0.47	--	--
Alloy 740	0.03	0.45	0.27	1.02	24.3	49.4	0.52	--	--	1.83	19.6	1.58Ti
Alloy 347	0.04	0.31	1.87	Bal.	17.3	10.0	--	--	--	0.56	--	.01Ta
347 HFG	0.09	0.41	1.46	--	18.4	11.98	--	--	--	0.9	--	--
HR-120	0.06	0.65	0.46	Bal.	24.1	38.2	0.33	--	--	--	0.09	--
Alloy 617	0.07	0.5	0.5	1.5	22.0	52.0	9.0	0.3	--	--	12.5	.12Al
Alloy 800H	0.07	0.27	0.76	Bal.	19.5	32.3	--	--	--	--	--	--
IN52 Cladding	--	0.36	--	9.25	29.2	59.9	--	--	--	--	--	1.29(Al+Ti)
IN72 Cladding	--	0.26	--	3.21	42.9	53.0	--	--	--	--	--	.61Ti

Task 5 – Corrosion Model Development

Approach

- Evaluate corrosion database generated from Task 4
- Develop corrosion models
  - Sulfidation on furnace walls
  - Coal ash (hot) corrosion on superheaters snd reheaters
- Formulate predictive equations
  - Correlate corrosion with coal chemistry
  - Consider thermodynamics and kinetics
  - Apply scientific and engineering principles
  - Avoid empirical correlation
  - Professor R. A. Rapp serves as consultant
- Incorporate prior B&W corrosion data, if applicable

Summary

- **Task 1 –**
  - **Coal databases evaluated to-date**
    - B&W Coal Database
    - Penn State Coal Database
    - USGS Coal Database
  - **Key parameters**
    - Sulfur
    - Chlorine
    - Na + K
    - Ca + Mg
    - BAR
  - **Over 20 coal mines identified**
- **Tasks 2 and 3 –**
  - **BYU combustion facility in preparation**
- **Task 4 –**
  - **B&W laboratory testing facilities ready**

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